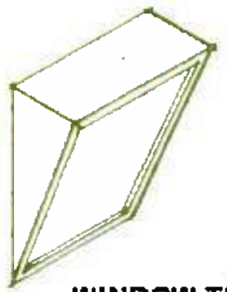
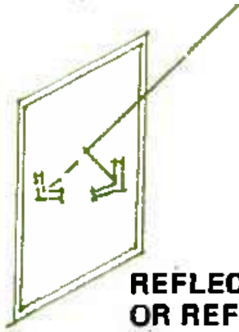
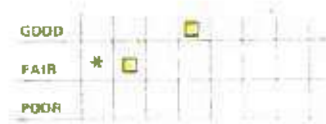


WINDOW TILT

Ventilation, maintenance and expense depends upon the types of window installed



REFLECTIVE GLASS
OR REFLECTIVE FILM



Characteristics depend upon type of window unit and glazing

General Lighting

Proper lighting considerations can save energy and avoid some heat load by optimizing the use of natural daylight and effectively using artificial light. Light hitting a surface is measured or expressed in foot-candles.

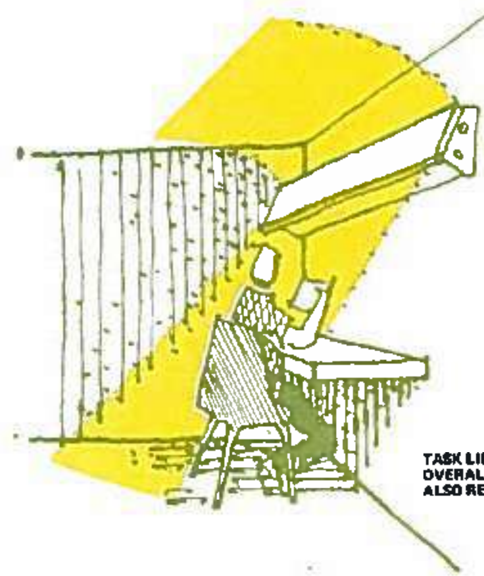
For general lighting, 10 to 30 footcandles are satisfactory. Goals at specific areas should be:

	Average Footcandles	Range Footcandles
sink	75	50 to 100
range and work surface	75	50 to 100
reading	75	50 to 100
shaving and makeup	30	20 to 50
sewing	150	100 to 200
desk	75	50 to 100
table games	30	20 to 50

Lighting to the eye is relative to other factors such as brightness (amount of light emitted or reflected from the viewed object), and contrast with the surroundings.

QUALITY OF LIGHT IS MOST IMPORTANT. THE QUANTITY OF LIGHT CAN VARY GREATLY. 5000 FOOTCANDLES OF DIFFUSED LIGHT UNDERNEATH A SHADE TREE CAN BE PLEASANT WHILE DIRECT GLARE FROM ONLY A 25 WATT BULB MAY BE IRRITATING.

The preferred task lighting levels will vary slightly between individuals. Use of artificial light can be conserved by tailoring it to the specific need. Dimmers, baffles, diffuser, reflectors and many small lamps allow customizing of the illumination of the task, rather than flooding the whole room with light.



TASK LIGHTING CAN REDUCE OVERALL LIGHTING COST AND ALSO REDUCE HEAT GAIN.

When selecting new fixtures fluorescent lamps should be considered. These operate considerably cheaper and generate less heat than standard incandescent, although their very white light may be unacceptable in some situations, such as make-up mirrors. There are certain disadvantages from using fluorescent fixtures, including relatively high initial costs and dimmers generally not being economically feasible. Incandescent is still the most popular lighting for social areas where mood is a consideration.

An indirect or diffused light usually feels more comfortable than a direct light source as the high intensity or glare is not seen by the eye. Glare can also be reduced by proper selection of light diffusers. Eye strain can also be minimized by raising the background brightness until the task and background areas are of equal brightness. A single light fixture may combine task lighting and general lighting needs depending upon location.

Contrast lighting can draw attention to an object, produce shadows and display textures. It is helpful in delineating outline, size and detail; however for extended viewing contrast creates eye strain, as the eye adjusts to the average brightness and still receives some light at high brightness; contrast ratios of up to 3 to 1 are generally acceptable.

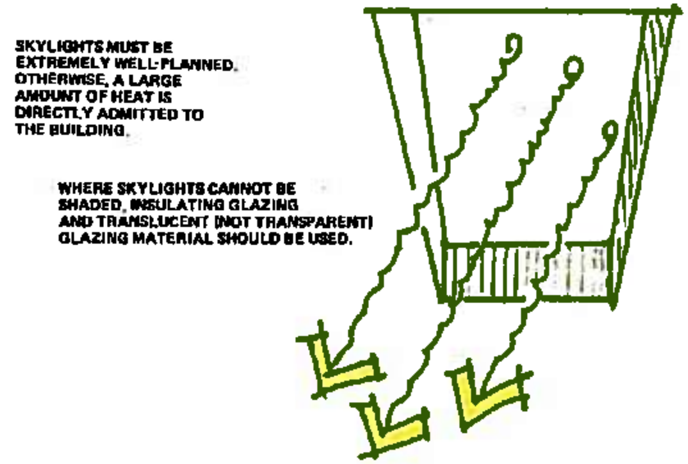
Other useful tools in maximizing the energy efficiency of general lighting are to include photocells, timers and dimmers. Photo-cells on exterior lights such as entrance lights or carport lights prevent forgetting to turn lights off during the day. Timers are valuable where lights are planned that will only be used for certain hours of the evening. Dimmers allow the adjusting of the artificial light intensity to the task. They are not only good energy savers but allow a variety of lighting changes within a space without altering light fixtures. Dimmers also augment task lighting plans.

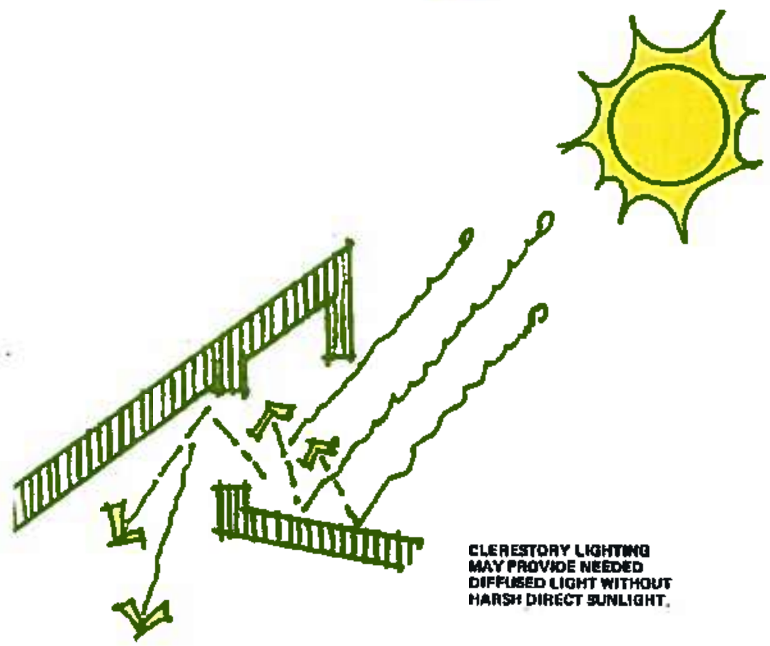
Daylighting

Daylighting is the age-old use of natural sunlight to light interior surroundings. Before the dependence upon artificial light, the science of daylighting was well defined and well used. More recently, prior to the energy crisis, its use had greatly diminished and been almost forgotten.

In the tropics there is an abundance of sunshine all year. People seek the shade rather than the direct light, but indirect daylight brightens an interior, adds life and makes it more pleasant.

Daylighting must be designed carefully to avoid adding too much heat load to the interior spaces. This generally means the use of indirect sunlight and avoidance of direct sunlight.





Daylight generally enters a space through windows, either in the wall, the roof (skylight) or at a second level wall (clerestory). Doors and other openings may also provide lighting.

Proper placement of windows involves careful planning to eliminate glare and contrast. Windows near adjacent walks or ceilings can use those surfaces to reflect light throughout the room spreading the light more evenly. This also reduces glare since the view from such windows is very indirect from most of the room. A window in the middle of a wall would cause high contrast and glare between the brightness of the window and the indirectly lighted wall. Such excessive contrast can be somewhat reduced by keeping the wall with the opening in a light or bright color.

Glare at windows can be reduced by the positioning of shading devices to limit the view of the sky to about 15 degrees above the horizon, or the use of low shrubs to block reflected light from water or other surfaces.

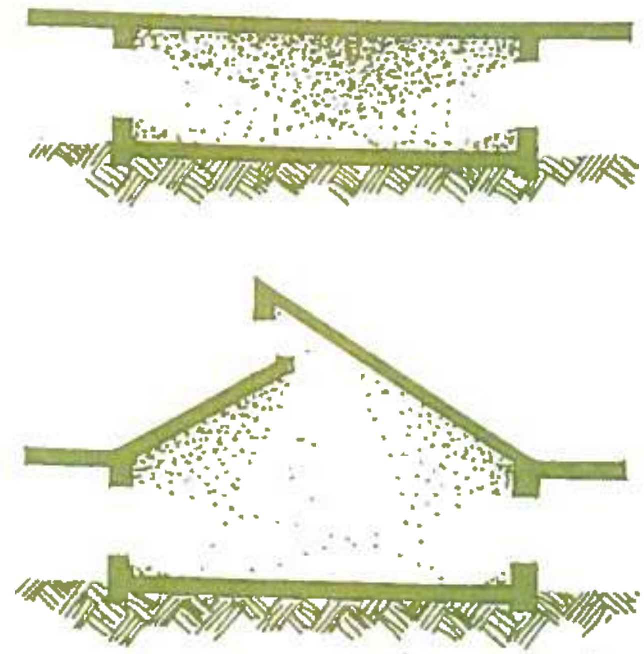
Lighting levels drop off drastically as you move away from a source (window, skylight or light fixture) as the light is dispersed by a factor of volume.

Light levels from more than one source can simply be added to find the footcandles at the specific position. The problem is how to distribute the lighting from the perimeter back into the rooms. One of the more effective ways is to use reflective surfaces to bounce the extra light concentrated at a window back up to the ceiling and down again further inside the space. This can be done by a light shelf seven or eight feet above the floor or with venetian blinds. At skylights this can be done by a curved reflector suspended below the opening.

FOR PROPER DAYLIGHTING, A SERIOUS STUDY OF THE VARIOUS DESIRED LIGHT LEVELS SHOULD BE MADE. IN SOME INSTANCES, CERTAIN AREAS ARE TO BE HIGHLIGHTED WHILE IN OTHERS, A MORE UNIFORM LIGHT DISTRIBUTION IS DESIRED.

DAYLIGHTING

LIGHT FROM ONLY ONE SIDE FAILS TO PENETRATE INTERIOR SPACE EVENLY.



DAYLIGHTING

CLERESTORY LIGHTING HELPS LIGHT INTERIOR AREA AWAY FROM PERIMETER WALL WINDOWS.

The level of daylight is dependent upon the reflectance level of various surfaces. Exterior ground or water surfaces, or nearby walls or vegetation affect the light hitting the window. The reflectance level of walls, louvers or blinds, ceilings or floor effect the interior distribution.

The level of natural lighting can be estimated, but is subject to many variables. To demonstrate the approach formulas are indicated below. For more detailed study, reference books on daylighting design and professionals familiar with the references should be consulted.

For a window in a wall the amount of light received at a point inside a room measured in footcandles is dependent upon the availability and intensity of exterior light and estimated by the following:

$$\text{Footcandles at a point} = \frac{10 \times W \times H^2}{D\,(D^2 + H^2)} + \frac{4Ag\ \ R}{Af\ (1\text{-}R)} \times \text{(exterior intensities)}$$

$$\times \ \text{(shading coefficient)} \ \times \ \text{(reflectance factor of exterior surface - if reflected light involved)}$$

Where

Af is the number of square feet in the floor area

H is the number of feet the top of the window is above the reference plane.

W is the number of feet of the window width.

D is the number of feet in the perpendicular horizontal distance of the reference point from the window.

Ag is the number of square feet in the actual area of glass.

R is the average reflectance of the wall (i.e., 50 percent for light or 20 percent for dark).

For a skylight or clerestory light at a point inside is estimated as follows:

Footcandles at a point F x U x Ag/Af x (exterior intensities) x (shading coefficient x (reflectance factor of exterior surfaces if reflected light is involved)

F is percentage of skydome (the hemispherical shaped dome of visable sky) exposed to the skylight or clerestory.

U is a general coefficient of utilization:

	dark colored walls	light colored walls
skylight horizontal	0.3	0.4
60 degrees angle from horizontal skylight	0.2	0.25
vertical clerestory	0.15	0.2

Ag is area of glass

Af is area of the floor we expect to light

These factors are multiplied by the amount of footcandles expected at various times of the day to see the amount of footcandles at the point of concern. If a shading element is involved, the figure will be multiplied by the appropriate shading coefficient indicated on the shading device charts.

Average figures for our island for the number of footcandles delivered by the sky, based on the average 55 percent of possible sunshine and March 21 and September 21 intensities are:

8:00 a.m. and 4:00 p.m.	3940
10:00 a.m. and 2:00 p.m.	5115
noon	5300

Minimum average expected values may also be useful, based on December 21 and December average possible sunshine of 52 percent these are:

8:00 a.m. and 4:00 p.m.	2450
10:00 a.m. and 2:00 p.m.	4080
noon	4485

The figures are dependent upon a location's latitude.

The amount of daylighting footcandles available can be increased by the reflective percentage if a reflective material is used on an exterior surface of a projected distance equal to the height to the top of the window. For example, a concrete driveway or patio will reflect considerably increased light to a sliding glass door.

	Reflectance Percentage
concrete	55
white	55 - 75
asphalt	7
grass	30
ground cover	25

One helpful way to study daylighting is to build a model. Light is a physical phenomenon that does not have a spatial scale; therefore a building can be scaled down and still permit accurate measurements of lighting levels. The model's surfaces will need to be approximately the same reflectance as the actual building. Use of a light meter that measures footcandles can establish ratios of light experienced at a position versus the light available outside. Preferably, the model should be tested at the proposed building site so that it can model such local conditions as reflections from landscaping or adjacent buildings. Passage of seasons can be simulated by tilting the model to the proper relationship.

For those who wish general guidelines without detailed calculations, the following items can be expected to improve the quality and quantity of daylighting:

Daylighting may be more important in daily general activity areas than in resting spaces or spaces that require electric lighting anyway.

Take extra care when using morning and afternoon sun for daylighting due to their low angle and heat gain problem.

Use light colored ceilings and walls to increase reflection of light.

Use light colored gravel immediately in front of windows to reflect light from the ground outside to the ceiling inside.

Place windows close to areas desired to be lighted, i. e., sinks and desks.

Windows off courtyards or alcoves often give good indirect lighting.

Clerestory windows or skylights introduce light deep into rooms; care must be used to handle the direct sun and to waterproof these window assemblies.

Combine skylights with electric lighting to provide a consistent light source over an activity area.

Translucent materials such as glass blocks offer a diffused light source while blocking some of the heat gain that comes through transparent glass. This is especially effective against early morning and late afternoon sun.

Provide adequare shading of the window, both top and sides to block direct sun and glare.

Use low landscaping to reduce glare reflected from nearby ocean or other highly reflective surfaces.

Canvas, fiberglass roof panels or other translucent materials will soften the direct sunlight for a patio or general activity area.

Psychological Cooling

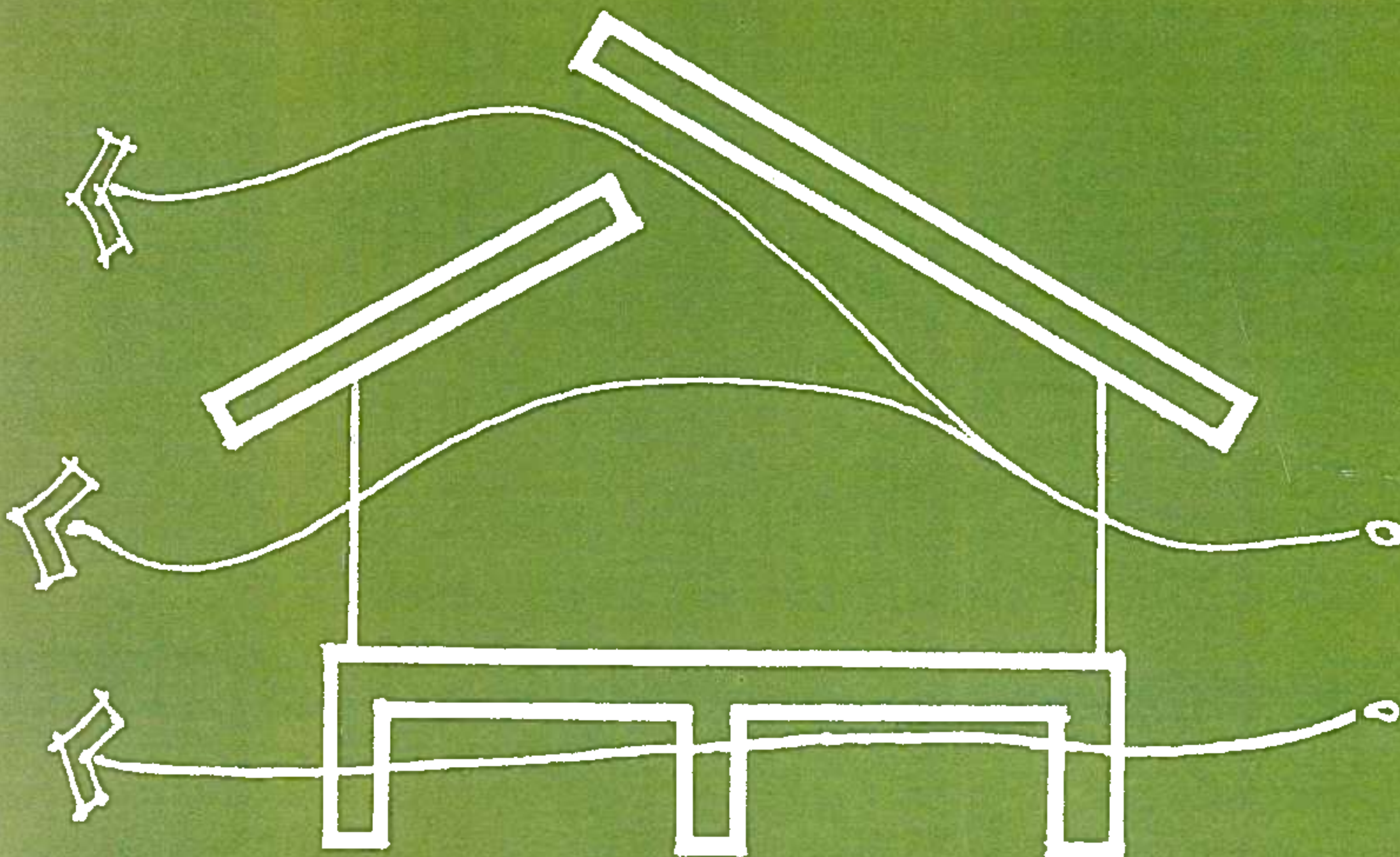
Cooling affects physical and psychological comfort and must be coordinated by the designer. Effective use of color will increase a person's sense of comfort in a space.

Dark colors exposed to direct sun will absorb more solar radiation than highly reflective colors, thus exterior building surfaces exposed to direct sun should be highly reflective such as white or light yellow. Surfaces orientated to reflect light onto the building or into windows (such as fins or louvers) might be painted dark to avoid glare to the interior.

Some colors are considered psychologically cool (restful) since their long wave length is less stressful to the eye; such colors are greens, blues and violets. Whites, browns and blacks are considered neutral. "Hot" (stimulating) colors--yellows, oranges and reds--should be used sparingly. While most of the impact is psychological, excited individuals burn up more energy (and consequently give off slightly more heat) than more relaxed people.

The tropics worldwide are renowned for bright colors that abound both throughout nature and the manmade environment. Such colors should also be considered in various aspects of residential design. Thus any color scheme should consider many design factors including psychological affects prior to the selection of materials and colors.

Chapter 3
Natural Ventilation



Naturally Ventilated Houses

A major approach to providing comfort in residences while achieving energy efficiency is to employ the techniques of natural ventilation. Choice of ventilation methods will be based on the interrelated comfort principles, climatic conditions, specific site conditions and lifestyle.

The conditions identified in the standard comfort zone generally apply to slightly active people clothed for a temperate climate zone and with an air velocity below 10 feet per minute (essentially still air). This condition does not consider comfort when the air motion relative to occupants is "lively" or "breezy"– which is a nontechnical description of a comfortable environment in hot weather. People in summer clothing, with 85F (29.4C), 70 percent RH can be quite comfortable when there is a 2-3 mile per hour breeze. Psychologically, in warm weather, the movement of air relative to people is a pleasant sensation and greatly increases the feeling of comfort.

When there is a perceptible air velocity as little as 2-3 miles per hour there is striking change in conditions for thermal environmental comfort. An average person would normally require 73F (22.8C) for 90 percent RH, whereas, 78F (25.6C) becomes comfortable with the breeze. Thus proper ventilation may make people feel 5F (2.8C) cooler even with relatively slow air motion.

If people can be comfortable in what is normally considered a hot, humid condition because of a steady breeze, this principle should be adapted to design. An average velocity of 2-3 miles per hour can be easily tolerated by occupants. It does not rustle papers or give a feeling of draft to most people. A 5-8 mile per hour breeze is still gentle, will flutter papers and mess hair and may be nearer the upper limit for comfort. With 80 percent RH, 85F (29.4C) and a wind of 2-3 miles per hour there would be an effective temperative of 78F, (25.6C) which is acceptable to most people.

Natural ventilation provides for three distinct functions – for air supply, for convective and evaporative cooling and for psychological cooling.

Ventilation is necessary to keep interior temperature and humidity from increasing due to heat output associated with human activity. Exhausts such as range hoods and bathroom exhaust fans aid ventilation. House plants add to the humidity and increase the need for ventilation.

Buildings with louvered, vented and windowed walls that are planned for natural ventilation should be orientated to fully take advantage of prevailing breezes. The orientation of a building and the location of windows must also consider sun angles to minimize heat gain. Skillful use of building elements such as screen walls, projecting canopies and landscaping can help induce ventilation and provide sun protection.

Air exerts a pressure as it strikes a building. The greatest pressure occurs on the windward side when the wall is at a right angle to the wind direction. As the air blows over and around the building a low pressure area is created on the leeward side.

Air moves from high pressure to low pressure. With openings in both the windward and leeward sides, an airflow is created within the building. Maximum velocity will occur when small openings are on the windward side where the pressure is the greatest and large openings on the leeward side, the optimum ratio being 1:2.

The next task is to use the basic principles of air flow to develop good natural ventilation. How can a building be planned to take advantage of the movement of air, alleviate influences of the sun and humidity and provide for comfortable and safe living? Factors to be considered in the proper planning of such a building are:

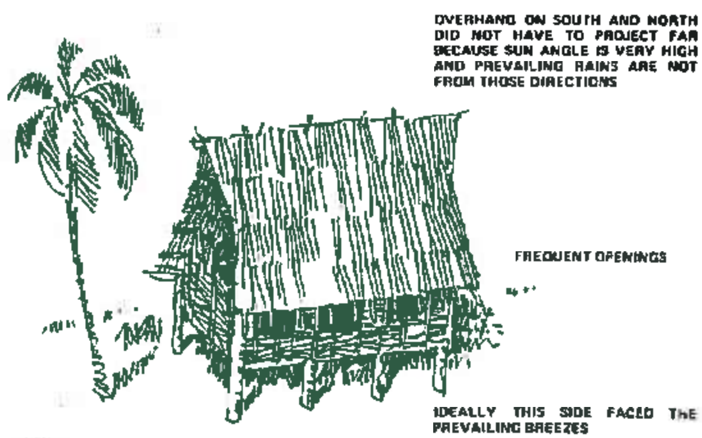
Building configuration.
Location of interior spaces and outdoor spaces.
Roof shapes.
Windows and openings.
Shade and sun control.
Landscaping and vegetation.
Induced ventilation.
Traditional architectural solutions.

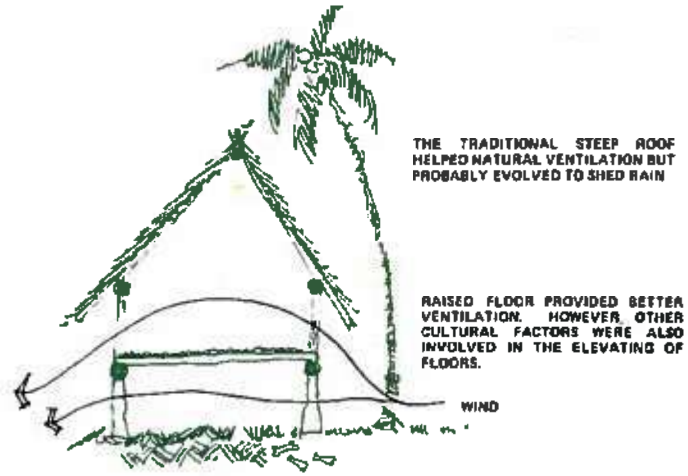
Building Configurations

Generally, the shape of a building should be elongated with the longest side facing toward the wind. Ideally, the long sides should be away from the east and west sun, but this is not always possible because the prevailing breezes often come from these directions. Recommended building proportions are 1:1.5 to 1:2 for the short side compared to the long side facing the wind. For our island, this will result in a relatively long narrow building directed east-northeast.

For two-story structures, the air flow through the first floor is good although slowed somewhat by ground friction. Because of the pressure build-up, wind will be forced over the structure and therefore a provision such as an overhang or canopy will help to redirect the wind horizontally into the structure.

Elevating a structure on stilts minimizes the resistance near ground level and in fact greatly improves air distribution by allowing air to circulate freely on all sides, including under a structure. Raising the building also gets away from the humidity of the heavier low air and elevates the structure above the level of low bushes that block or slow the breezes down. This concept was well understood in early stilt houses. With later design the lower bodegas, or store rooms, were enclosed by thick coral stone and mortar walls which blocked wind under the structure.





Two-story structures provide other advantages such as reduction of roof area and the solar insulation effect of upper floors. Also, a stronger wind occurs at 20-40 feet above the ground.

Transition spaces such as gardens, lanais, porches, verandas, terraces and breezeways can serve to direct the breeze while providing added protection from the sun's direct heat.

Location of Interior and Exterior Spaces

The planning of functions and spaces to take advantage and to promote natural ventilation is of great importance, since the occupants of a building will seek those spaces where their comfort can be satisfied.

During the daylight hours, the living room, dining, patio areas, kitchen, recreation and work rooms receive the most use. These areas should be located for the best exposure to ventilation and natural light. A transition space such as a hallway can be utilized as a means of channeling air movement to areas not directly exposed to the wind.

Spaces may be stacked such as bedrooms over living room to gain better exposure for more rooms or to take advantage of the fact that air rises as it is warmed, and thereby induces ventilation.

The kitchen, bath and other utility areas should be on the leeward side of incoming breezes so heat, humidity and smell can be dissipated without contaminating adjacent areas. Waterheaters, freezers, washers and some other heat and humidity generators can be located outside the general living spaces.

Bedrooms are occupied generally during night hours when breezes and air movement are slow or non-existent. Still, the bedrooms should be located to receive the cooler outside air whose temperature has dropped approximately 10 degrees.

Where bedrooms are clustered in one general area, efforts should be made to provide for the free movement of air through them.

Naturally ventilated spaces appear larger because sound does not reverberate as much as in a totally closed room, thus some rooms can be smaller, and more economical to construct.

Closets and storerooms can be located along unshaded exterior walls to buffer the heat load to major living spaces.

A patio, screened-in porch or courtyard can serve as a secondary activity area for some functions and be economically naturally ventilated and lighted. Thus construction may be less expensive by allowing the basic house structure to be smaller since it doesn't need to accommodate the patio functions. The design of the exterior space must still consider its effect on natural ventilation and sunlight just as described for the interior spaces.

Roof Shapes

The roof is a major building element that can greatly influence natural ventilation.

A roof generally will not produce temperatures cooler than the outdoor air, but if well designed, it can prevent indoor temperature from increasing above outdoor air temperature, thus keep the ceiling temperature about the same level as the surrounding surfaces.

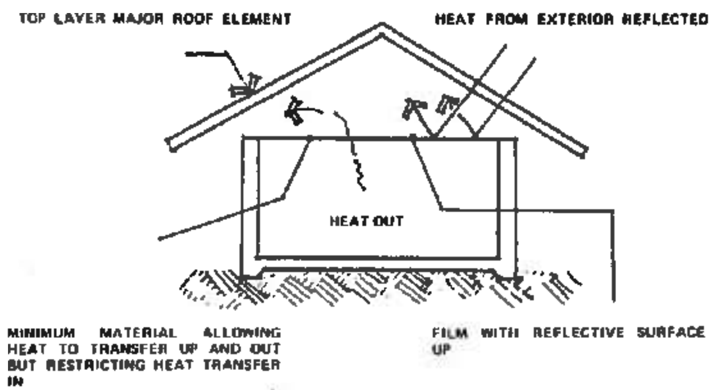
A major consideration is to have roofs constructed of low thermal capacity, using materials of lightweight construction or providing good heat resistance. Insulation is desirable in cases where a heavy concrete or tile roof is necessary or preferred.

Another consideration is the shape of the roof. The roof shape can provide a natural method for moving air through a building. As air gets warmer, it expands, becomes lighter and rises to the highest point in the space. A sloped roof will direct the movement of hot air up and out through vents provided at the top. A roof shape that effectively promotes natural ventilation in tropical climates is the hip type roof, with gable vents and long overhangs. This allows hot air to rise and escape while providing protection from direct sunlight and rain.

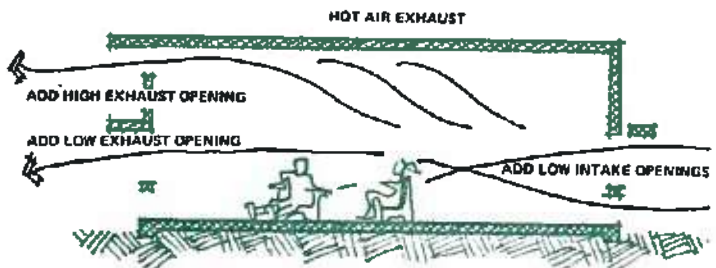
In addition, the roof construction space itself should be vented at the top and bottom so air flows between the roofing and ceiling. Natural air currents will keep the space cooler and carry away the radiant heat gain coming trough the roof. Openings to this air cavity must be a minimum of 1/150 of the ceiling area.

A roof configuration can evolve into an upper and lower roof. The upper roof could be only a shade element or a roof trellis.

Conversely, the upper roof could be the major element and the lower roof element of minimum material allowing heat to transfer out of the space when the interior is warmer than the exterior air.



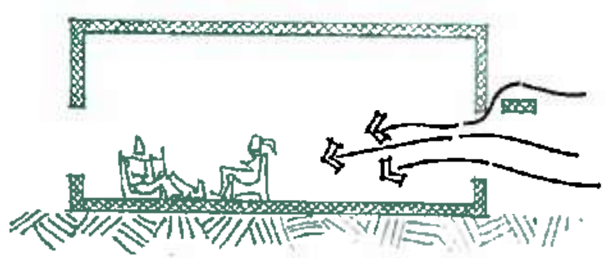
Common but often inappropriate for the tropics, a typical low flat roof tends to collect warm air inside its construction and radiate heat down to the occupants.



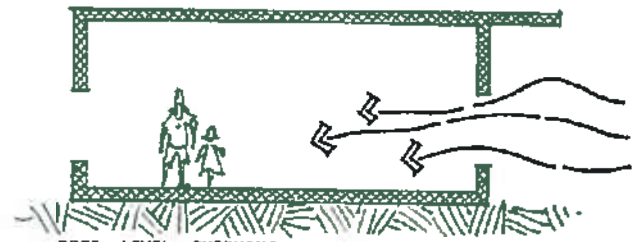
ADDITIONAL OPENINGS WILL INCREASE THE SPEED AND EFFECTIVENESS OF AIR PASSAGE THROUGH THE HOUSE.

Roof overhangs are significant elements of a tropical roof. Wide overhangs, particularly, on the exposed east, south and west walls not only give needed shade to walls from solar heat gain but also provide an outdoor transition space which can be used as a veranda or patio. Overhangs and window canopies can affect the interior air circulation.

EYEBROW OVERHANG–AIR MOVES UPWARD



SLOT OR LOUVER OVERHANG– AIR DEFLECTED LOWER



ROOF LEVEL OVERHANG– AIR DEFLECTED LOWER

OVERHANGS AFFECT THE AIR CIRCULATION THROUGH THE INTERIOR

Ceiling height is an important consideration. In an air-conditioned space this is decreased to minimize the volume of air to be conditioned, whereas in other structures this should be high to decrease radiation of heat from the ceiling materials.

Induced ventilation will occur with a solar chimney that uses rising hot air to draw fresh air into the building, even when the roof is flat.

The chimney has a clear material on one side to admit the sun's heat and dark solid material on the other three sides. The sun heats the air in the chimney which then rises, drawing new air in, preferably from low vents near shady outside areas. A 2-foot square chimney 6-foot high over a 10-foot by 12-foot by 8-foot high room can easily create a better than 2 mile per hour breeze.

Windows and Openings

Ventilation occurs through windows, doors and other openings such as exhaust ports. While windows serve various functions including daylighting and viewing, the primary concern for a naturally ventilated house is the ventilation capability. The windows for such a structure should be plentiful. The orientation depends upon the direction of prevailing breezes as previously discussed.

Windows should be located at a variety of heights to permit air movement at various levels. This minimizes stagnant air pockets. Proper circulation may also be achieved by having the intake openings at a low level on the windward side and at both low and high levels on the leeward walls. Low windows encourage air flow at a level where human activity normally occurs. High windows on the leeward side assist in exhausting hot air and induce ventilation by natural convection.

Windows are a potential source of large heat gain into the interior and require careful placement and shading to minimize the heat transfer. They are also a potential problem area for water infiltration. The strong winds and heavy rains common to the tropics make watertight windows a necessity. Proper sealing of joints, placement of gaskets and continued maintenance of the entire window assembly is important.

Shade and Sun Control

In addition to air movement or ventilation, solar heat gain is the other element in a warm humid island climate than can be easily controlled to maintain physical comfort.

Control of the effects of the sun on a building will influence the inside temperature. A decrease in the radiant heat gain will consequently reduce the amount of heat that must be removed. By providing devices for shading, the solar heat gain can be drastically reduced and shaded surfaces can be of a lower R value, which are usually less expensive. Surfaces are not required by building codes to be insulated to any particular R value when the building is not air conditioned.

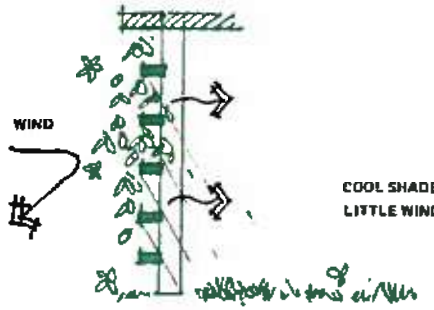
Landscaping and Vegetation

Landscaping can have a significant cooling effect, and can be an energy saver through proper site planning and the selection of plant materials. Proper landscaping design will help control solar heat gain, humidity, direct breezes and augment rain protection.

Two facts stand out as illustrations of the importance of landscape and vegetation. First, the rough dark leaf texture and volume of a tree or shrub diffuses and absorbs solar radiation and provides shade. Second, the temperature of grassed areas on sunny days are 10 to 15 degrees cooler than those over bare ground or paved surfaces. Ground cover and low growing vegetation absorb the heat that would be reflected into the air, or onto walls and into windows.

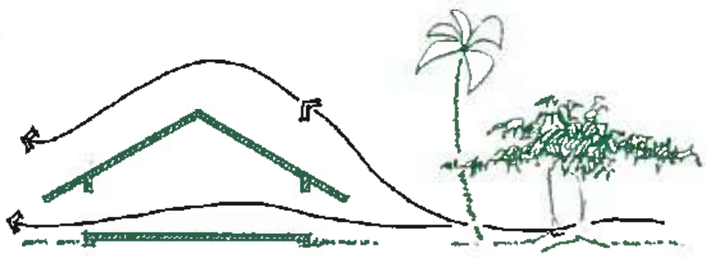
Selection of plant types and locations must also consider what effect a particular plant or tree will have on the prevailing breezes as well as what effects it will have on shading and humidity.

Dense plant material on a trellis will provide shade which will be cooler than a space exposed to full sun. But such dense material on a vertical trellis will also restrict welcome breezes and will increase humidi .
Some trees provide daytime shade but close leaflets in the evening, decreasing their resistance to wind and minimizing humidity build-up (i.e., flame tree, yellow poinciana and monkey pod).



VERTICAL TRELLIS

In other cases, dense vegetation can be arranged around a building to funnel and direct breezes through the building or along the surface of a building.

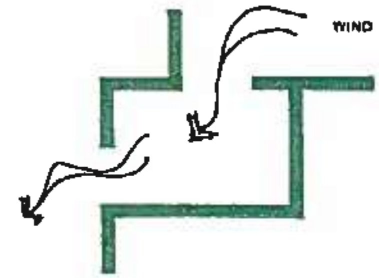


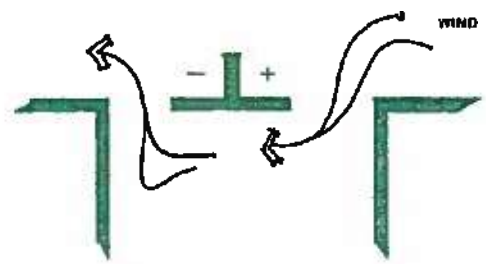
With our island's breezes normally coming from the east, planting on this side should be either below or high above building openings. The low planting will not hinder the breeze, however, a tall tree has the benefit of providing shade from the morning sun and a funneling effect on the breeze under it.

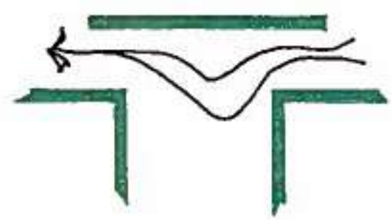
Plants on the north and south need to be taller or closer to building walls to have a shading effect. These can also be used to direct airflow along walls or at windows.

TO SHADE STRUCTURES TREES NEED TO BE HIGH WHEN LOCATED ON SOUTH SIDE

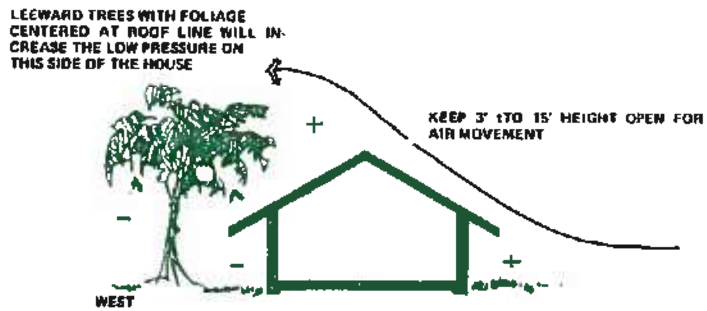
LANDSCAPING EFFECT ON AIR MOVEMENT






INDUCED AIR MOVEMENT FOR ROOMS NOT DIRECTLY EXPOSED TO WIND

High trees on the leeward side, if too close to a building, will tend to reduce wind speed through a building. Therefore, a careful balance must be achieved because shade is needed on this exposure. Leeward trees with foliage centered at the roof line will increase the low pressure area on this side of the house, increasing interior ventilation.



Induced Ventilation

Interior wind induced ventilation velocity can be estimated through the following calculations:

$$M = EAV$$

M is air flow in cubic feet per minute.

E is effectiveness of the opening (0.5 for openings perpendicular to the wind)

A is the actual open area of windows (use the smaller of either the inlet or outlet, and reduce to 80 percent to account for screens and mullions)

V is the wind velocity in feet per minute (miles per hour figure multiplied by 88)

We can compare the estimated ventilation with the flow required to get the number of air changes desired. The residential minimum number of air changes is one half the volume per hour.

The rate of air movement inside the building can be estimated from the above results as follows: We take the cross-sectional area of the incoming air and approximate the size of the air stream. After the air comes through the window it spreads out a bit, so a 3 feet x 4 feet window might have an estimated air stream of 5 feet x 6 feet. The interior velocity is:

$$V_I = \frac{M}{A_s}$$

V_I is interior velocity in feet per minute.

A_s is the area of the air stream in square feet.

M is air flow in cubic feet per minute.

This result can be used in evaluating the effective temperature of the space, assuming the occupants are in the air flow, as previously discussed.

The amount of ventilation induced thermally can be calculated. This is the ventilation that occurs when no wind is present; it results from the inside warm air rising and going out upper openings, and cooler air coming in the lower openings to replace the exhausted air.

$$M = 9.4A\sqrt{h\,(\Delta t)}$$

M is air flow thermally induced, in cubic feet per minute.

A is area of opening (smallest of either upper or lower openings in square feet).

h is average height difference between inlet and outlet in feet.

Δt is the numerical difference between exterior and interior temperature in F.

The temperature difference can be assumed to be at least 1/2F per foot of the average height difference.

This thermally induced ventilation can be increased by raising the height of the outlet opening, increasing the area of the windows or creating a further temperature rise at the outlet.

Normally induced ventilation would be designed to compliment the wind ventilation, so for our island the high outlets would face west, or within 45 degrees angle of the west. Facing to the southwest would allow the use of the afternoon sun to increase the temperature at the outlets and thereby induce more ventilation.

Calculations are done to find the effect of the wind ventilation combined with the induced ventilation, as they cannot simply be added.

is combined air flow; cubic feet per minute.

is largest component, either wind or thermal induced; cubic feet per minute.

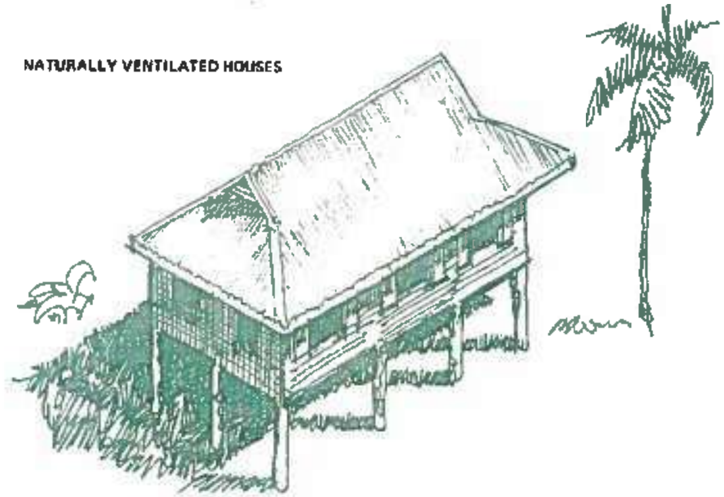
is smallest component; cubic feet per minute.

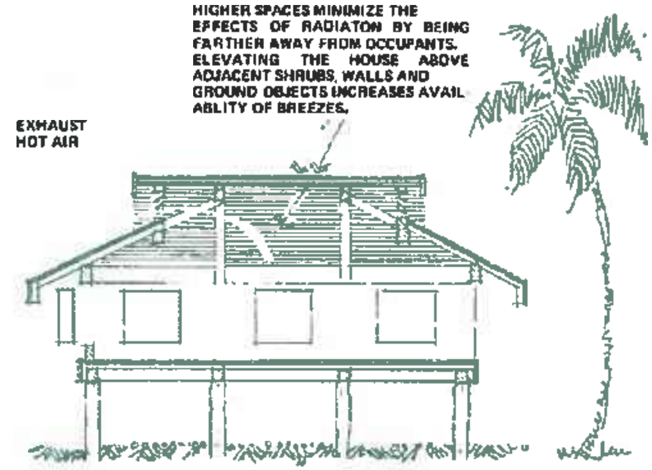
Where ventilation cannot be easily induced it may be desirable to reduce relative humidity by increasing the temperature. This is done by localized heating elements in closets, closed bookshelves or pianos. If heating elements are not used, venting should be provided for closets and cabinets to avoid humidity build-up. The air should be allowed to enter at the top and exit at the bottom, after absorbing moisture and thus weight.

Traditional Architectural Solutions

Traditional architecture has some particular techniques and concepts that are good examples of energy conscious designs. These concepts can be applied in today's structures.

Early island residences had high ceilings which allowed hot air to rise away from the occupants, and provided a greater distance from heat reradiating from the ceiling. The traditional wood framing and roof form economically provided the higher space; present concrete construction could effectively use the same concept.

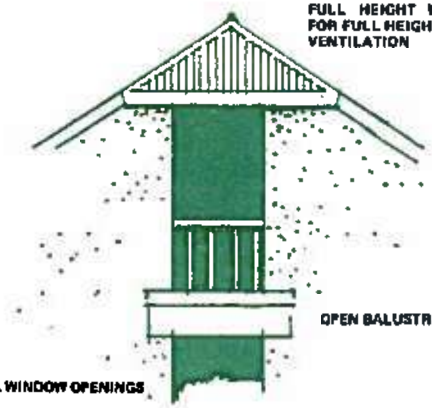




ELEVATING THE HOUSE ABOVE ADJACENT SHRUBS, WALLS AND GROUND OBJECTS INCREASES AVAILABILITY OF BREEZES

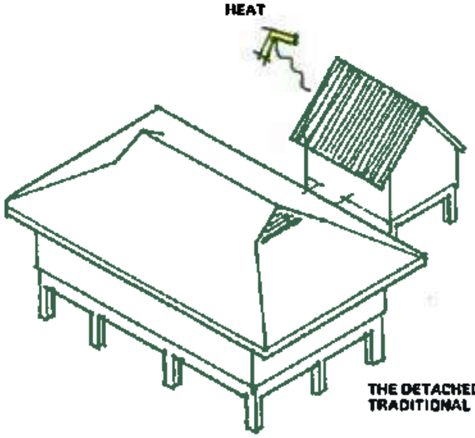
ELEVATING THE HOUSE MOVES IT AWAY FROM THE LAYER OF STILL, HUMID AIR DIRECTLY ADJACENT TO GROUND COVER.
WIND CAN TRAVEL THROUGH THE HOUSE AT GREATER SPEED BECAUSE OF THE REDUCED OVERALL WIND RESISTANCE AFFORDED BY THE RAISED STRUCTURE.

Full height windows were frequently used to gain ventilation. Sometimes these had open balustrades or balconies to provide privacy or safety, yet allow breezes for good ventilation.

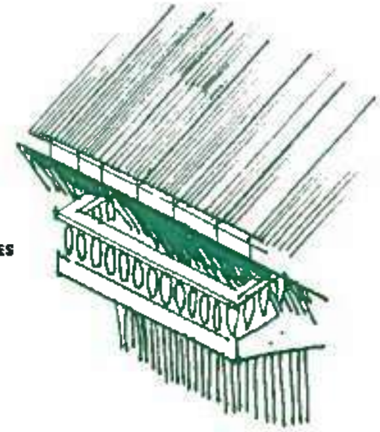


A detached kitchen has long been a part of the island's architecture. This separated the kitchen heat and smoke from the other areas of the house and allowed for easier, more open ventilation of the kitchen. This has been passed down to today's barbecue and occasional outside party kitchens.

New residences could beneficially reconsider the concept of a kitchen separated from the rest of the house by a breezeway.



Balconies, entrance porches and verandas are common throughout the region, especially in areas of previous Spanish influence. These provided raised, breezy, comfortable spaces away from the enclosed interior spaces, and made use of areas under long overhangs that shade the walls. These served as meeting and conversation spaces at the front of houses for evening relaxation.



Naturally Ventilated Residences

The following tropical residences have been designed and constructed using the concepts and principles previously reviewed:

Franke House
McCully - Cadmus House
Winkler Residence
Wiseman Residence
Batcheller House
Hawaii Energy House

Franke House

The Franke House is designed to take maximum advantage of the naturalness of a beachside property on the leeward coast of Guam.

The house is naturally ventilated throughout. Windows encircle the residence providing vistas of the surrounding areas: the ocean to the southeast and northeast, an island directly to the west and a backdrop of mountains to the east. The windows are especially concentrated on the windward and leeward sides for good cross ventilation. The recessed entry is angled into the wind and combines to further induce the air through the house.

The first floor is elevated on concrete columns 4-5 feet above grade with the adjacent ground bermed up at various redwood decks and stairs. By elevating the structure the building's wind resistance is reduced and the living levels are further elevated above the surrounding ground cover. The additional height also offers further protection from storm inundation and provides boat storage.

The two-story interior is organized around an open central core that in turn opens to ocean side balconies at two different levels. Open spaces above beams and louvered doors throughout add further to the interior air circulation, especially at the upper level where the open center is bound by bedrooms on both sides. Relatively high ceilings at both levels permit ceiling fans for all major rooms.

The structure combines a concrete exterior building envelope with a wood second floor and exterior decks. The walls and roof are polyurethane waffle construction with cement plaster on the interior and concrete on the exterior. The roof and walls (other than windows) have a "U" value of approximately 20.

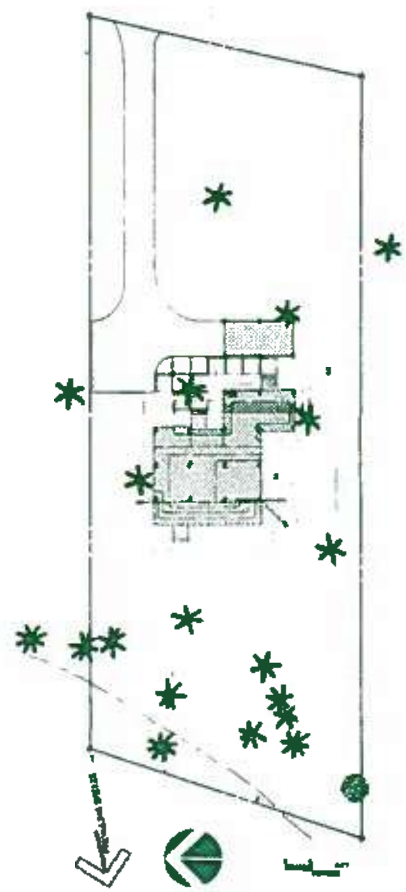
The interior plaster surfaces and ceramic tile and marble first floor offer cool surrounding surfaces throughout.

The windows are primarily horizontal sliders. These are protected from rain and direct sun by projecting sunscreens which further provide security and typhoon protection when closed.

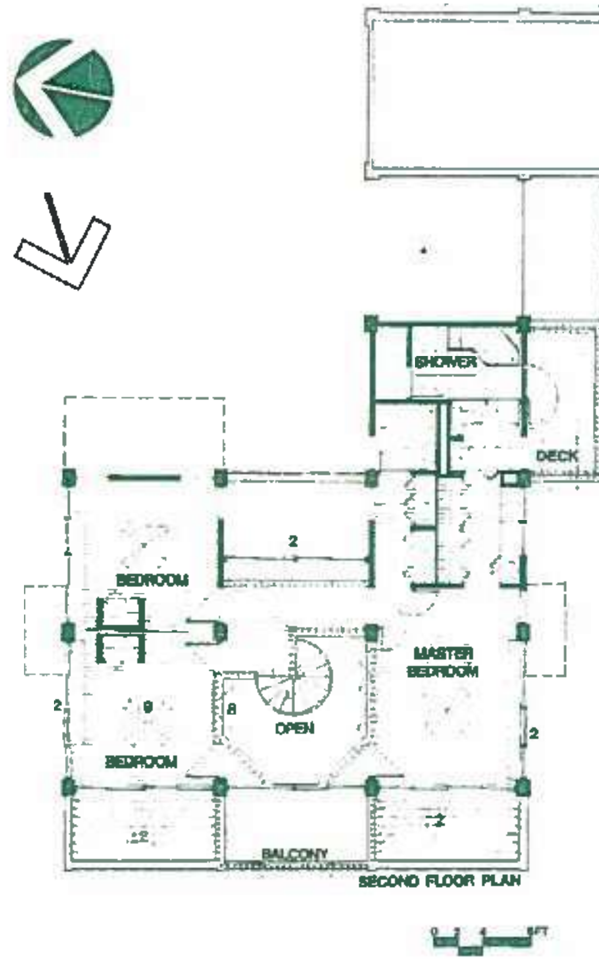
A thermo syphon hot water system is used.

Overall, many of the energy-conscious features are simply an adaptation of traditional island details that have been used for centuries. These details include the elevated floors, high ceilings and tilt-down sunscreen shutters.

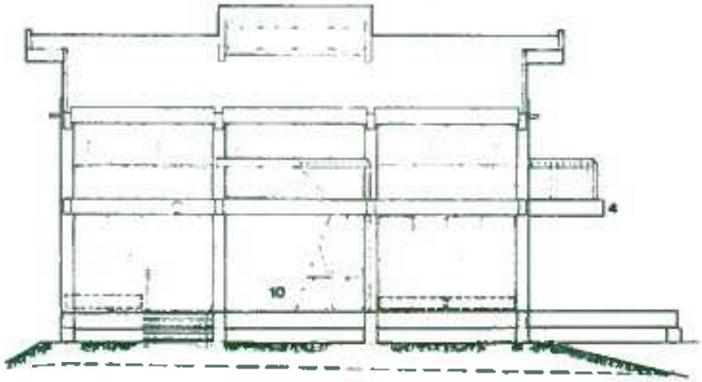
Project: Residence for Mr. & Mrs. Milt Franke
Architect: J.B. Jones, Architect, AIA
Contractor: Self-constructed
Construction Date: Under construction



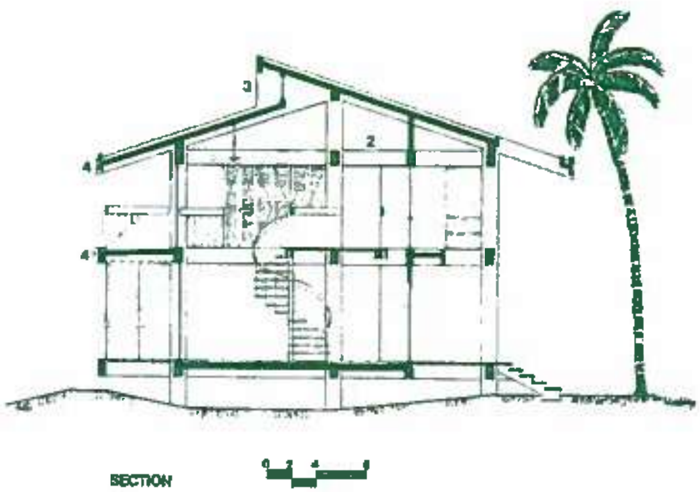
1. House sited to take maximum advantage of prevailing winds.
2. Existing tall palm trees preserved.
3. First floor is elevated providing increased ventilation and boat storage beneath structure.



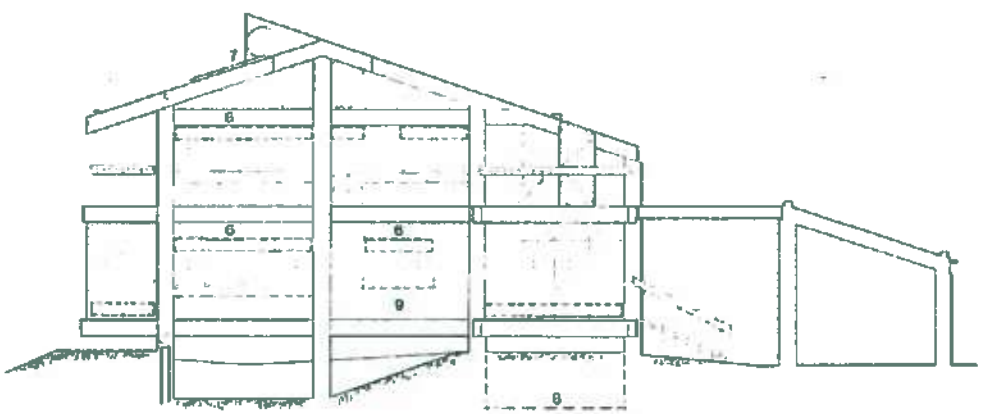
1. House orientated toward prevailing breeze.
2. Large quantity of windows especially on windward and leeward sides.
3. Ample decks and porch space for transitions between exterior and interior spaces.
4. Ceramic tile first floor provides cool surface.
5. Building configuration helps induce wind through central core of the building.
6. Kitchen ventilation direct to exterior.
7. Exterior shower.
8. Louvered bifold doors permit additional interior air movement.
9. Ceiling fans to augment air circulation.



BEACH SIDE (WEST) ELEVATION



SECTION



SOUTH ELEVATION

1. Elevated structure minimizes wind resistance.
2. High, open interiors permit maximum air movement.
3. Clerestory opening for warm air exhaust.
4. Wide roof and floor cantilevers for sun shading.
5. Louvered doors provide cross ventilation and maintain visual privacy.
6. Sunscreens provide protection from direct sun, rain and serve as typhoon and security protection in louvered position.
7. Thermo-syphon hot water system.
8. Provision for future water catchment system.
9. Walls constructed of urethane waffle and plaster system providing excellent insulation.
10. Maximum quality of openings provided.
11. Ceiling fans to augment interior air movement.

McCully-Cadmus House

Project: Residence For Duncan McCully and Molly Cadmus
Architect: Taniguchi-Ruth, AIA & Associates
Contractor: Builcon Corporation
Construction Date: August 1982

This naturally ventilated house located on the beach extends indoor living space through a variety of porches and terraces. Covered by a large sheltering roof, the outdoor spaces provide protection from sun and rain, and offer flexibility in living arrangements. The house is raised four feet on stilts for protection from heavy seas and to promote the cooling effects of air movement under as well as around the structure.

The house uses open planning of interior spaces to take advantage of free-flowing natural breezes to every room. A central clerestory at the peak of the roof, with louver windows facing downwind, dominates the high ceiling of the living room and bedroom areas. Warm air is expelled naturally by means of the chimney effect while the high windows provide a warm and interesting play of indirect light to the spaces below.

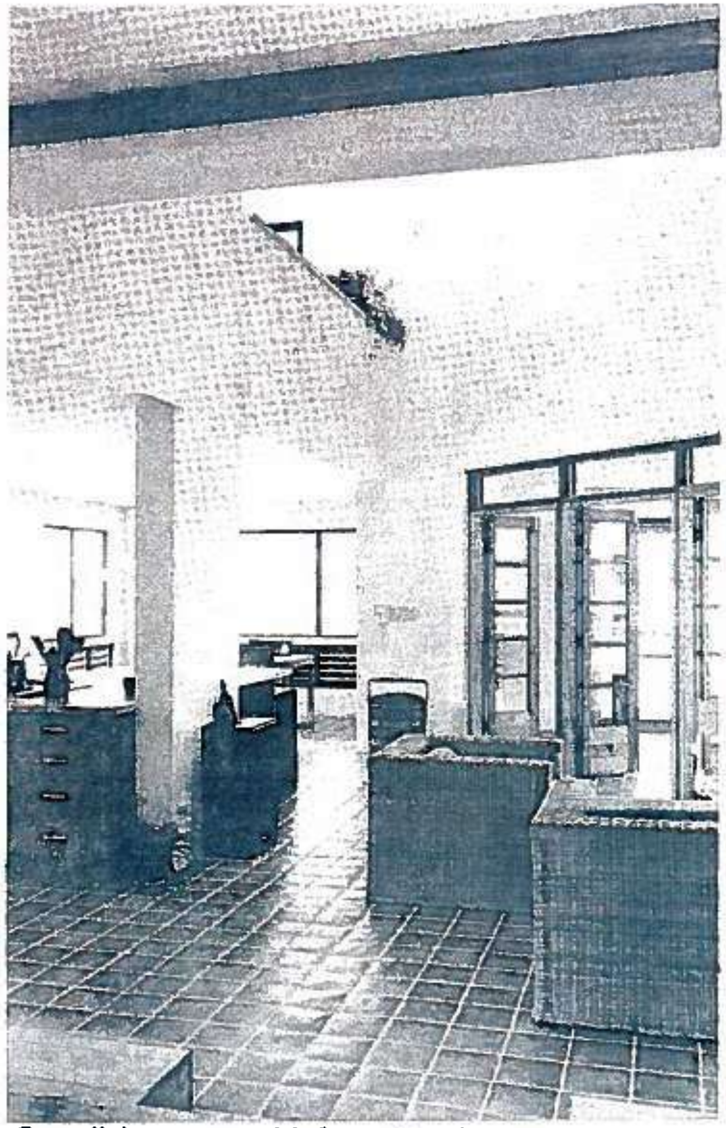
A combination of doors, louvers and sliding windows provide a variety of methods for introducing and controlling air flow through the house.

An outdoor screened porch adjacent to the living room provides an informal space for entertaining and relaxing by the ocean. The kitchen is located downwind of the other living spaces to exhaust cooking heat directly to the exterior. Lush tropical vegetation on the site was selectively thinned to enhance air movement and views.

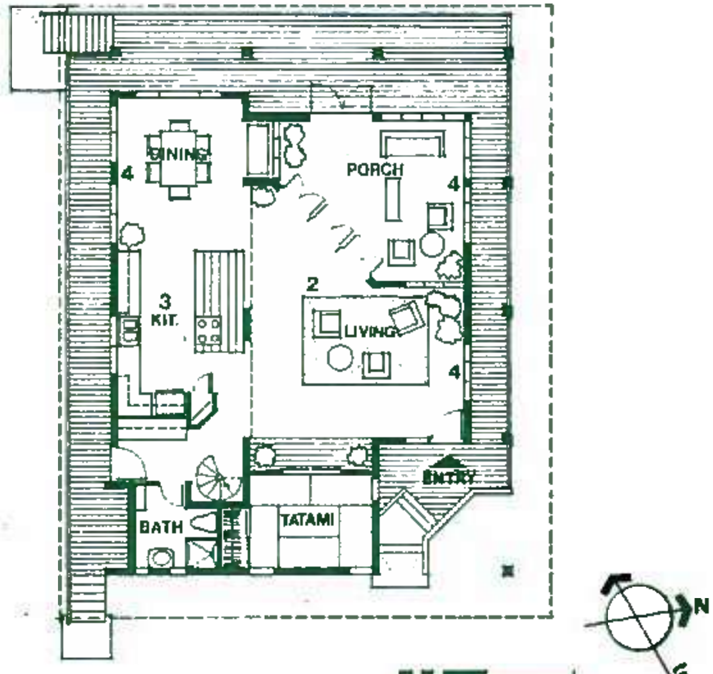
The house is constructed of reinforced concrete and masonry construction. Interior flooring is glazed ceramic tile for coolness and maintainability. Outdoor terraces have exposed redwood flooring.

A future addition, consisting of guest house and studio, is planned as a separate building connected to the main house by a covered walkway. Detachment of building elements in this way will provide maximum free area for natural ventilation and air movement for both buildings.

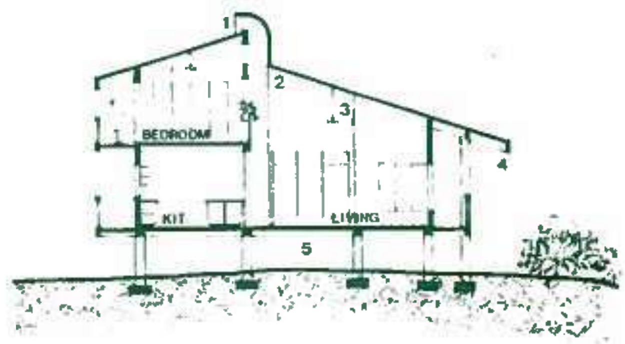
Living room with screened porch beyond.



Open living spaces with few separating walls promotes air circulation.



FLOOR PLAN



SECTION

1. Clerestory at high point exhausts heat
2. High ceiling in living area lets heat rise
3. Ceiling fans aid circulation
4. Windows protected by wide overhangs
5. Air circulation under house promotes cooling

Winkler Residence

The Winkler house was designed to take maximum advantage of a spectacular cliffline site on the windward coast of Guam.

It sits on an intermediate ledge of a 200-foot-high cliff overlooking the Pacific Ocean and coastal plateau below.

The narrow ledge prompted use of a linear plan with living spaces along a central circulation spine. Bedroom, dining and service spaces are on the upper level of the two-story home. A living room, library and children's den are on the lower floor. The living room is a two-story space that opens from the mezzanine - level dining area.

The house is divided into two main areas with separate wings for each. An open-air walkway connects the main areas and provides variety in the linear circulation spine.

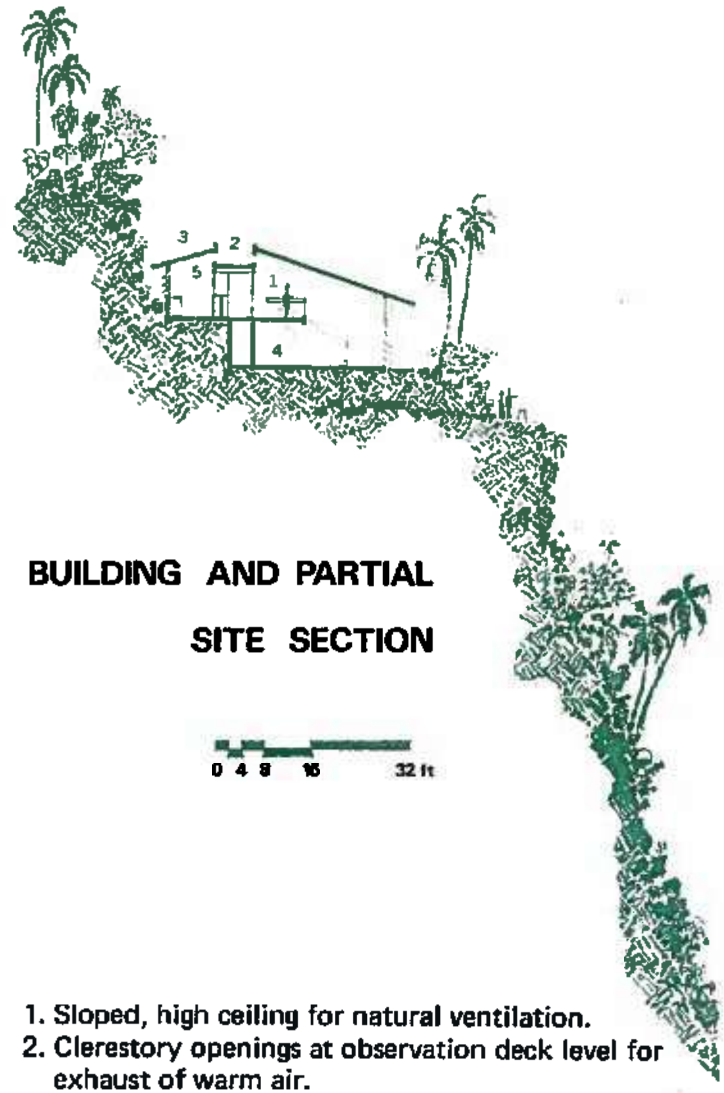
Projecting windows on the ocean side and high louvers in the corridor maintain comfortable air-flow ventilation. The sloped roof and high interior spaces encourage air movement and take advantage of convection.

Sloping overhangs limit direct sunlight at the upper level and the cantilevered second floor provides shade and rain protection for the lower floor. Lush, tropical surrounding landscape on the northeast and west elevations provide additional shade.

The roof is insulated with 2 inches of styrofoam with the roof painted white for reflectance. A large percentage of the building perimeter is nestled into the side of the cliff limiting overall heat gain. The central spine is designed for central air conditioning ducts and the window systems' locations and selection are compatible with air conditioning. However, the level of comfort from natural ventilation has precluded the need to install air conditioning.

Project: Dr. Paul Winkler Residence, Mangilao, Guam
Original owner: Judge Richard Benson and Dr. Joy Benson

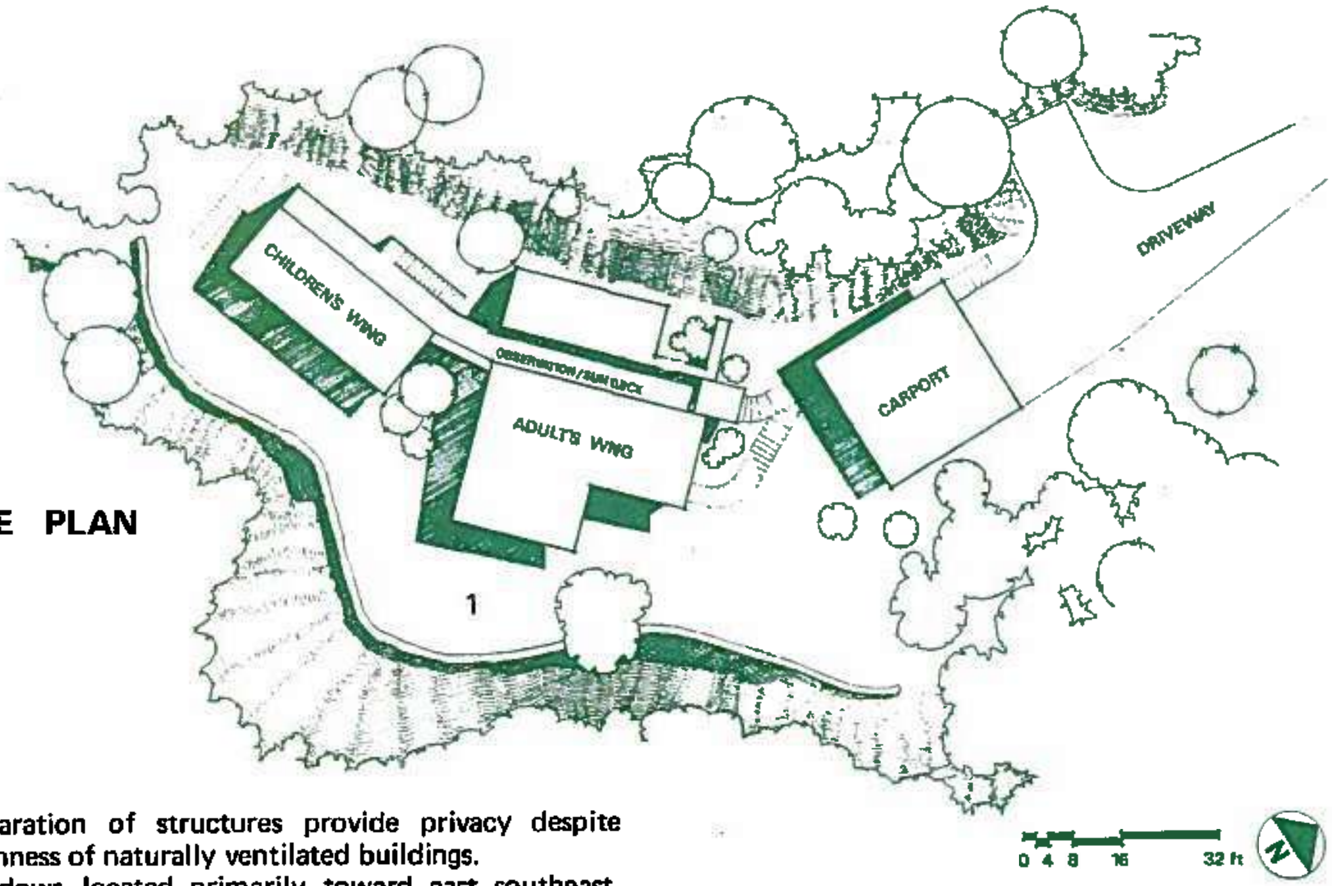
Architect: Jack B. Jones, AIA
Consultant: Jerry Hazelwood
Contractor: Phil/Guam Construction Co. and Pacific Construction Co., Inc.
Construction Date: 1974



BUILDING AND PARTIAL SITE SECTION

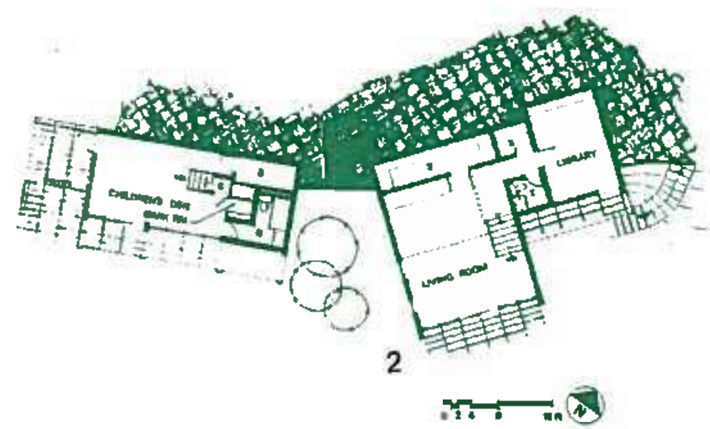
1. Sloped, high ceiling for natural ventilation.
2. Clerestory openings at observation deck level for exhaust of warm air.
3. Building nestled into edge of cliff reducing overall heat gain.
4. Building spaces stacked to minimize building envelope area.
5. Ceiling designed for future central air conditioning system.

SITE PLAN



1. Separation of structures provide privacy despite openness of naturally ventilated buildings.
2. Windows located primarily toward east southeast. This is toward main view and takes advantage of prevailing breezes.
3. Kitchen and toilets located on leeward side of house to facilitate immediate air exhaust.

UPPER LEVEL FLOOR PLAN



LOWER LEVEL FLOOR PLAN

Wiseman Residence

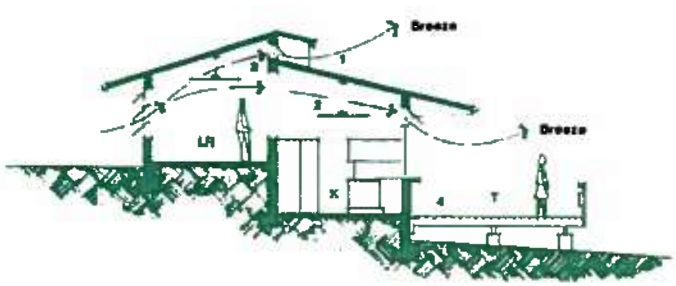
The house is tucked into the Donney Valley overlooking the Saipan Harbor area. The orientation in the valley provides for almost year-round funneled tradewind breezes. The house is orientated to take advantage of these tradewinds and provide natural ventilation in all rooms of the house.

The main area of the house has a spaciousness not readily apparent from the exterior. The living room entry and study area overlook the recessed family-dining and kitchen below. All these spaces face a window wall and woodframe terrace which open the space fully to the view of both the valley, harbor and beyond to the ocean.

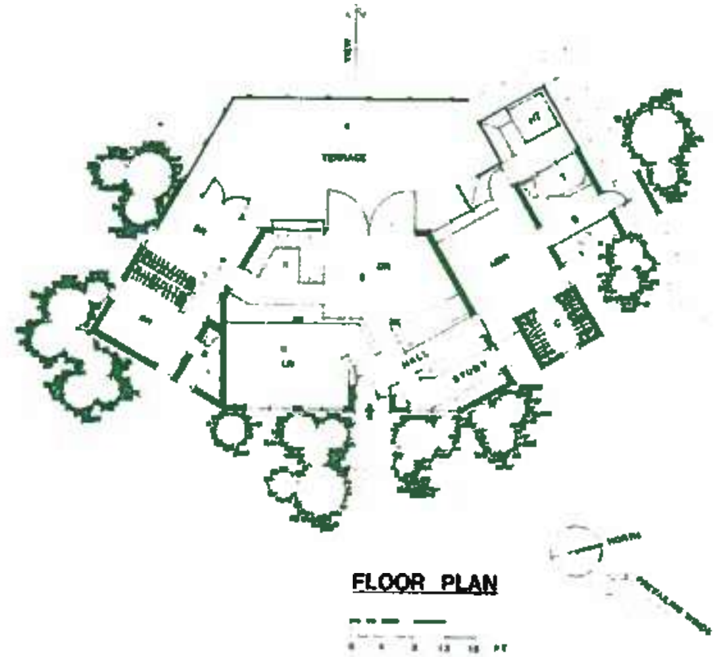
The interiors are handled with the same simple restraint as the structure. White-painted, plastered walls with quarry tile flooring echo the plastered walls and provide radiant cooling.

The siting of the building, ceiling heights with clerestory venting windows, varying floor levels and natural ventilation provide pleasant year-round tropical comfort.

Project: Residence for Mr. & Mrs. David Wiseman
Capitol Hill, Saipan
Architect: CM Group, Inc.
Contractor: Self
Construction Date: 1980



SECTION



FLOOR PLAN

1. Clerestory windows provide exhaust for warm air.
2. Ceiling fans augment air movement.
3. High, sloping interior spaces encourage air movement.
4. Wood terrace expands living area.
5. Open interior plan aids ventilation.
6. Tile surfaces aid interior comfort.

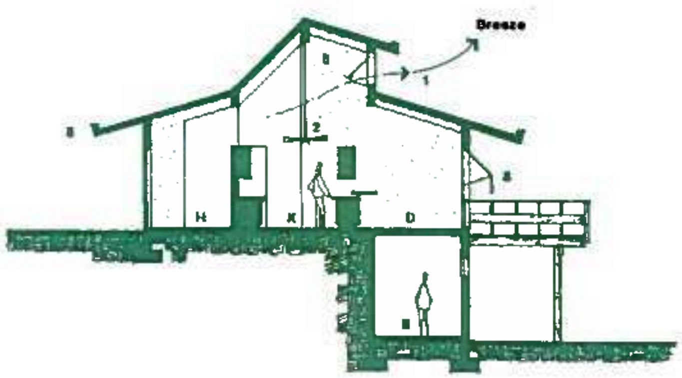
Batcheller House

Sitting on a high coral bluff the Batcheller Residence commands a panoramic view of the Saipan Lagoon and Philippine Sea. The direction of trade-winds and the site topography enabled the house to be orientated for view while still allowing "diagonal" year round unobstructed natural ventilation through the house.

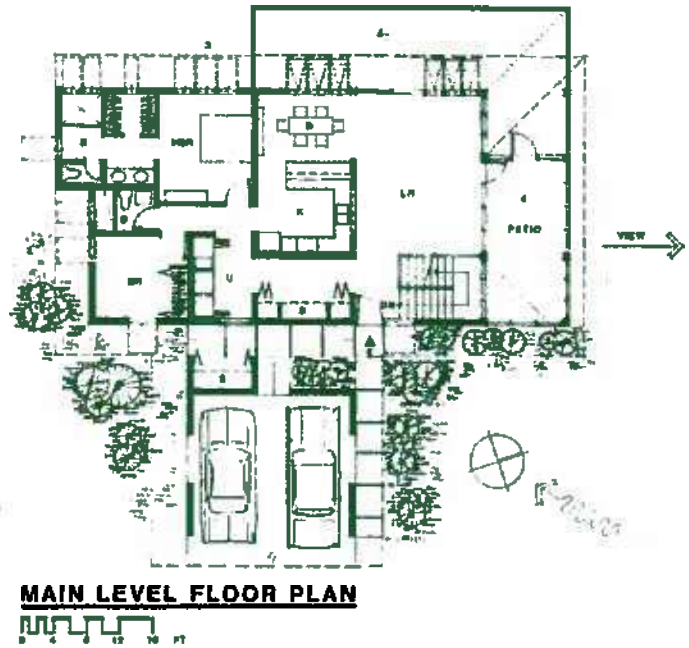
The residence provides open spaces blended together by the high ceiling and vaulted roof with clerestory windows running the full length of the house. Screened openings with aluminum Bahama shutters, two panel tilt-down louvered shutters, provide year round ventilation but prevent direct sunlight and wind-driven rain from entering.

The large wood frame lanai and screened patio provide added living area outside the building space, thus extending the usable space of the house.

Project: Residence for Mr. & Mrs. Kim Batcheller
Navy Hill, Saipan
Architect: CM Group, Inc.
Contractor: To be determined
Construction Date: 1983

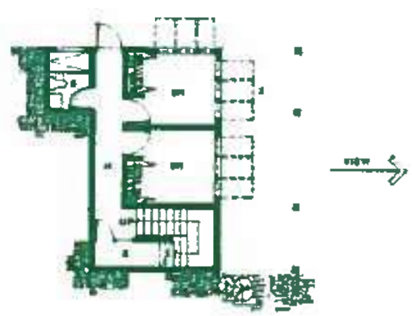


SECTION



MAIN LEVEL FLOOR PLAN

1. Clerestory windows provide exhaust for warm air.
2. Ceiling fans augment air movement.
3. "Palm Beach shutters" provide protection from rain and direct sunlight.
4. Wide deck and patio provide semi-enclosed spaces for tropical living.
5. Wide overhangs throughout minimizing heat gain.
6. High interior spaces encourage air flow and minimize heat reradiation from roof slabs.

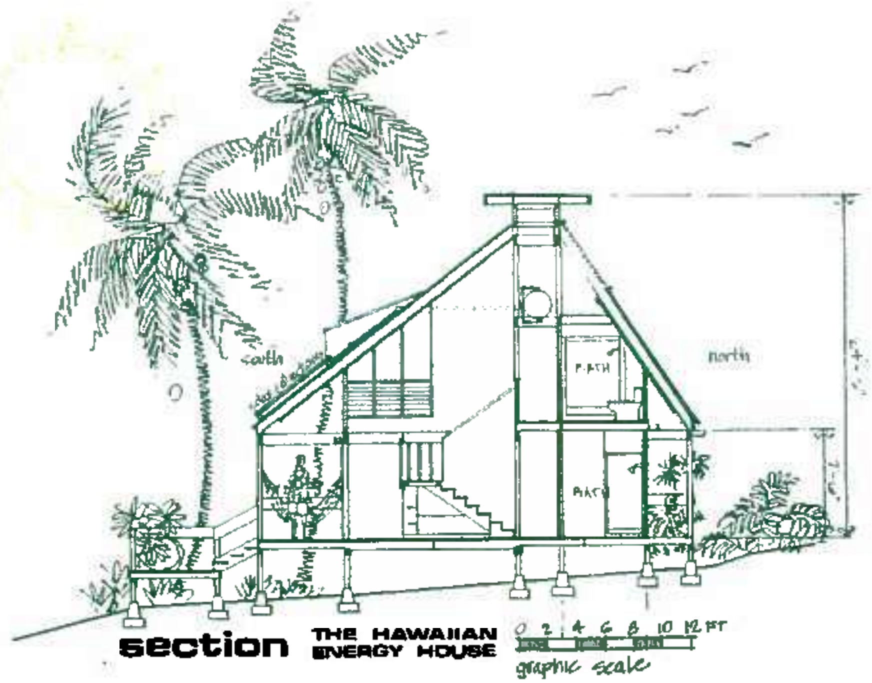


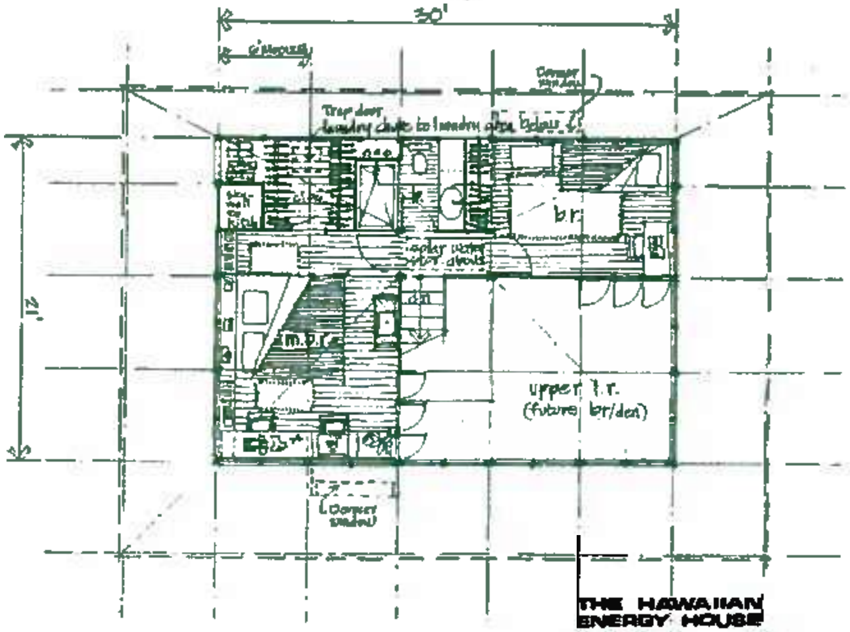
LOWER LEVEL FLOOR PLAN

Hawaii Energy House

The Hawaii Energy House has incorporated a multitude of energy saving features. The plans and sections of the structure are indicated below.

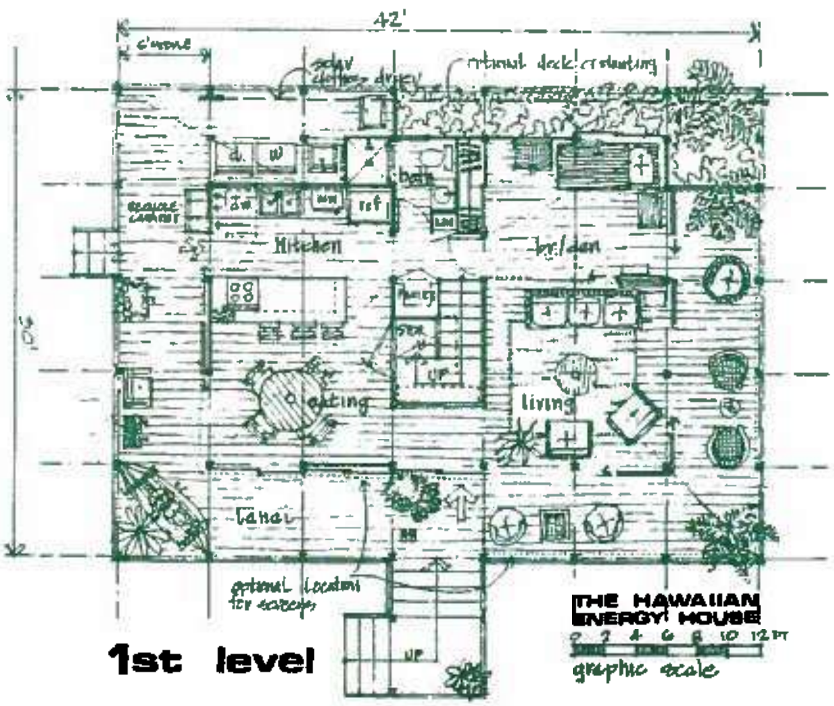
Reprinted from Hawaii Home Energy Book, by Jim Pearson. Copyright 1978 by the University Press of Hawaii.





2nd level

THE HAWAIIAN ENERGY HOUSE
graphic scale



1st level

THE HAWAIIAN ENERGY HOUSE
0 2 4 6 8 10 12 FT
graphic scale